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APPLICATION OF THE DIRECT READING EMISSION
SPECTROMETER IN PROCESS CONTROL

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APPLICATION OF THE DIRECT READING EMISSION
SPECTROMETER IN PROCESS CONTROL

(Shimazu Seisakusho, K. K.)

ABSTRACT

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Several modifications of the "Quantometer," "Quantograph," or grating polychromator (a type of direct reading emission spectrometer), currently in use throughout the various metal and alloy industries in Japan are described and evaluated. Among these are an improved vacuum version that extends into the ultraviolet region, a miniaturized version with ultrahigh-precision grating, and a computer that operates in conjunction with one or more spectrometers to provide automatic process control of several elements simultaneously. Formulation of the calibration curve is discussed. Details of the operation, advantages, limitations, and prospects of these instruments in application to the nonferrous metal, light metal, steel, cast iron, and automotive industries are presented. The introduction of the computer results in higher analytical reliability, self-checking capabilities, speedier analysis, fewer operator personnel, and on-line data processing. The possibility of applying the technique to powder and liquid metals and nonmetals is indicated. *Author*

1. INTRODUCTION

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With the advent of the direct reading spectrometer, emission spectrometers have been gaining in popularity as process analyzers. The first half of this

Numbers in the margin indicate pagination in the original foreign text.

paper presents an explanation and discussion of the vacuum Quantograph (Quantovac) and the Quantolette as the most typical spectrometers, and the Quantac (a quantometric automatic computer), which functions as an accessory with the former two. The second half of the paper describes the application of these instruments in the nonferrous metal, cast iron, and automotive industries.

Emission spectrometry is a method of analyzing elements by measuring the intensity of the line spectra emitted by a stimulated sample. When the sample is excited by an arc or spark, the elements contained in the sample emit characteristic line spectra. All other conditions being equal, the intensity of the line spectrum is proportional to the quantity of the respective elements. In other words, the elements contained in the sample can be quantitatively analyzed by measuring the intensity of their line spectra.

The photographic method has been used to measure the line spectra, but a more rapid method using photomultipliers has been developed in recent years. Many studies have been carried out in applying this method to process control and, accordingly, various types of direct reading spectrometers have emerged (refs. 2 to 4) since the appearance of the first so-called Quantometer in 1948 (ref. 1), and in situ analytical technique directly in the furnace has been put into practice by the aluminum industry. At the present time, almost 100 spectrometers are in use by light metal, steel, cast iron, and other manufacturers in Japan. Above all, automation of the analysis of converter (Bessemer) steels has been successfully realized by combining the Quantovac with a digital computer, which permits the results of the analysis to be teletyped to the furnace for further control of the converter process on the basis of the analytical results.

The advantages of the direct reading spectrometer are the following:

- 1) Rapid analysis; only a few minutes are required.
- 2) High accuracy; the average reproducibility falls within 1%, which is accurate enough for practical use.
- 3) Wide range of analysis; capable of analyzing the content of elements in the range from 0.005% to 25%.
- 4) C, P, S can be analyzed by means of the vacuum spectrometer.

In the ensuing paragraphs, the Quantovac, a type of direct reading spectrometer in widespread use during the last few years, the Quantac (a quantometric automatic computer unit), and the Quantolette, a very modern direct reading instrument, are described. An attempt is also made to survey the state-of-the-art of these direct reading spectrometers in application to chemical processing.

2. THE DIRECT READING SPECTROMETER

The Quantograph, or Quantometer, is a term used to describe a direct reading spectrometer which analyzes the spectrum above 200 Å obtained by means of a grating spectroscopy from a sample excited in air. A similar instrument, which utilizes the far ultraviolet region above 1600 Å in vacuum from a sample excited in an argon atmosphere, is called a vacuum Quantograph, or Quantovac.

Figure 1 shows the GK-200 vacuum Quantograph as the most typical representative of the spectrometers mentioned above. As further shown in figure 2, the sample is excited on the emission stand by a high-performance emission system. The emitted light passes through the entrance slit of a grating spectroscopy, where it impinges upon a concave diffraction grating.

The diffraction grating is a reflective surface with 1200 parallel lines etched at regular intervals, dispersing the incident light into its spectrum.

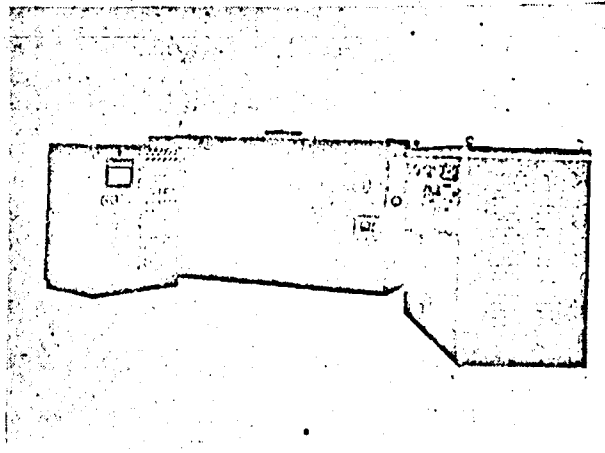


Figure 1. The Quantovac, a Direct Reading Spectrometer.

The exit slits are situated at the locations of the line spectrum corresponding to each element on the Rowland circle of the spectroscopy. The reflecting mirrors and photomultipliers are situated behind the slits.

The photomultipliers are connected to the measuring system, and the values corresponding to the contents of the respective elements are recorded automatically.

Referring to figure 2, it is supposed that the line spectrum of the standard element is received by the first photomultiplier through the first slit, the second photomultiplier receiving from the second slit the line spectrum of the element to be analyzed. The photomultipliers behind the slits yield a photocurrent, which charges the corresponding batteries; when the charge of the battery connected to the first photomultiplier reaches a certain value, the charge arriving at the second battery is cut off by actuation of the relay. In this way, the intensity ratio of the line spectrum for the principal element to be analyzed to that of the standard can be measured and a calibration curve compiled with a series of standard samples.

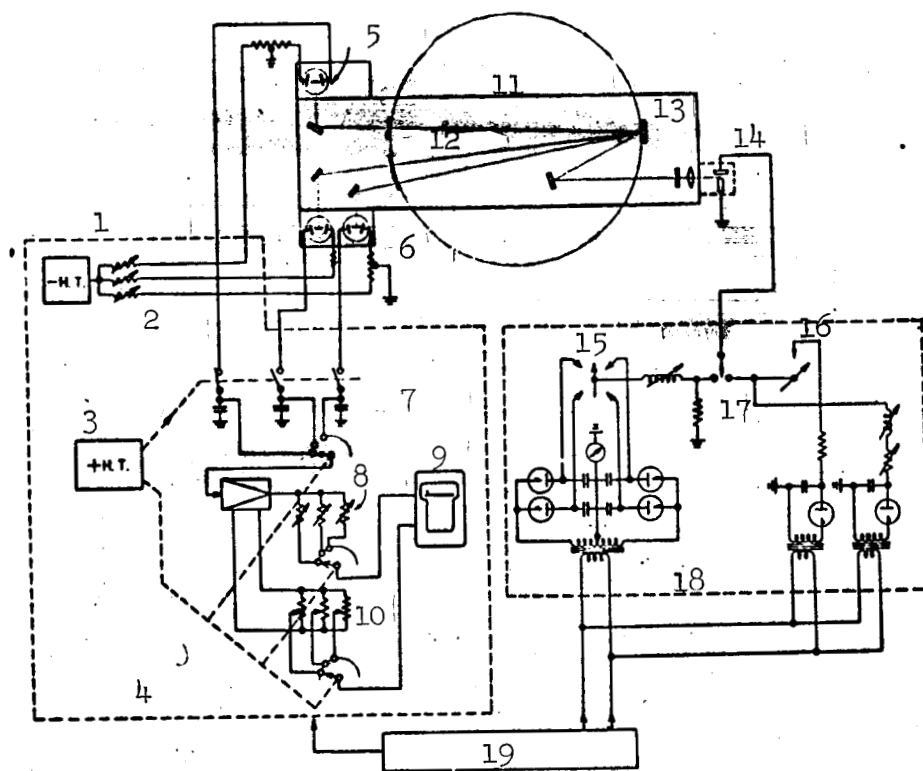


Figure 2. Schematic of a Vacuum Quantograph.

- 1) Negative high-voltage supply for photomultipliers; 2) Sensitivity adjustment of photomultiplier; 3) High-voltage supply for light intensity measuring system; 4) Light intensity measuring system; 5) Ultra-violet photomultiplier; 6) Visible-light photomultiplier; 7) Batteries for optical measuring system; 8) Sensitivity adjustment; 9) Recorder; 10) Zero-point adjustment; 11) Spectroscope; 12) Exit slits; 13) Diffraction grating; 14) Emission stand; 15) High-voltage dc spark circuit; 16) Multisource circuit; 17) Relay; 18) Model 3 high-performance emission apparatus; 19) Voltage stabilizer.

The vacuum Quantograph has certain distinct characteristics in comparison with the regular Quantograph used to analyze spectra in air. These characteristics are as follows:

1) In order to avoid absorption of the line spectra by the oxygen in the air, the internal part of the spectrometer is kept in vacuum, so that the range from 2000 to 1600 Å can be utilized. It also incorporates a special concave 1745 grating, which focuses light energy around 1800 Å.

2) The test sample is excited by an arc between solid silver electrodes in argon gas. Accordingly, the absorption of the spectra by oxygen in the air of the electrode housing can be avoided. Excitation by an arc discharge in argon yields a spectrum from three to eight times stronger than the spectrum obtained in air, which means that the spectra of trace elements can be analyzed with high sensitivity.

3) A highly sensitized photomultiplier coated with a very thin quartz film is used to measure the far ultraviolet spectrum.

With the above improvements, the vacuum Quantograph is capable of analyzing C: 1931 Å, P: 1775 Å, S: 1807 Å, which the regular Quantograph is unable to measure.

Moreover, the quantitative analysis of C, P, S traces in steel was first carried out with the vacuum Quantograph.

Since the GV-200 Quantovac contains 24 photomultipliers, it is capable of quantitative analysis, not only of C, P, S, but also simultaneous analysis of Si, Mn, Ni, Cr, Cu, No, V, W, Al, Sn, As, B, Co, Ti, Cd, Mg, Ca, Zr, Pb as well.

Also in widespread use, in addition to the Quantovac, are the GQ-220 Quantograph and the GQ-75 Quantolette. The performance characteristics of these three Quantographs are shown in Table 1.

TABLE 1

PERFORMANCE CHARACTERISTICS OF TYPICAL DIRECT READING SPECTROMETERS			
Spectrometer:	Quantovac GQ-200	Quantograph GQ-220	Quantolette GQ-75
Radius of curvature of concave grating (cm)	200	220	75
No. of lines per mm	1200	1200	2400
Dispersion (primary) (\AA)/mm)	4.1	3.8	5.5
Range of measured wave- lengths (\AA)	1700-3400	2000-5200	1900-4300
Atmosphere of electrode housing	argon	air	air, argon

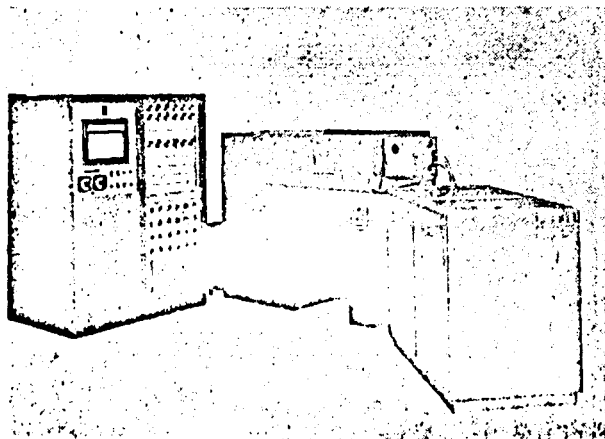


Figure 3. The Quantolette, a Direct Reading Spectrometer.

The Quantolette (fig. 3) is a small-scale Quantograph. A concave diffraction grating with 2400 engraved lines per millimeter is installed in the spectroscopy of the Quantolette. This is the most precise diffraction grating in the world. Only with this type of grating could the physical size be reduced without a concomitant penalty in resolution and dispersion. In summary, it has the following characteristics:

1) The illumination intensity of the spectroscope is increased fourfold over the conventional spectroscope.

2) Because the optical path is shorter, absorption by oxygen in the air is diminished accordingly. The quantitative analysis of C 1931 Å in steel or Sn 1899 Å in copper has been made possible with high accuracy, a feat that could not be realized in conventional spectrometers.

3) Thermal insulation can be accomplished quite easily, and the stability of the spectroscope is excellent. Because a temperature regulating system is built into the instrument, ancillary temperature-humidity equipment is not required, as explained in the next section.

The temperature regulating system of the Quantolette is shown in figure 4. Air circulates at constant temperature in the space between the two insulated walls of the spectroscope. Depending on the signal from the thermistor, the Silicon Controlled Rectifier (SCR) actuates a resistive element to control the 1746 heat produced by a heater or, if necessary, the SCR actuates a cooler to control the temperature of the circulating air. With this temperature regulating system, the relative gap between the slit and line spectrum becomes inconsequential in the face of outside temperature changes within $\pm 10^\circ$. By virtue of this system, the Quantolette is ready for use at any time and easy to operate by comparison with conventional direct reading spectrometers, which always require expensive constant-temperature equipment. Absolute long-term stability as well as accuracy are required of the emission and measuring systems used in the Quantolette and Quantovac. On the other hand, every possible measure must be taken to strengthen the reliability of the instrument, to ensure accessibility to service by the manufacturer, and to simplify inspection and maintenance, because trouble in any of the thousands of parts or circuit elements will disrupt

the process flow, which of course implies the loss of hundred thousands or even millions of yen.

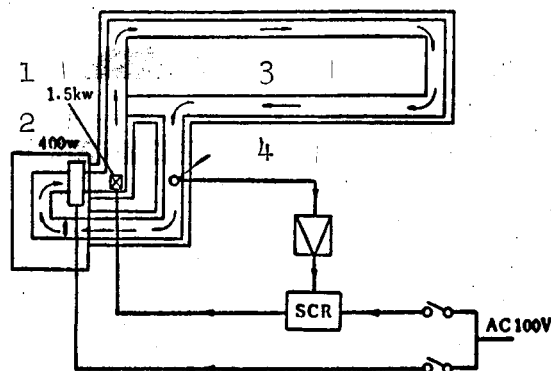


Figure 4. Temperature Regulating System of the Quantolette.

1) Heater; 2) Cooler; 3) Spectroscope; 4) Thermistor.

Inasmuch as it is often required to revise the programming of the instrument on short notice to comply with modifications of the manufacturing process, the spectrometer as an integral whole must be versatile. This means that each section of the instrument must be designed as a modular subsystem, with a "plug-in" feature.

The construction of the Model 240000 measuring system shown in figures 1 and 3 are designed to meet the above-mentioned requirements 100%, i.e., they are made up entirely of circuit modules and have wide versatility.

The Model 280000 emission system shown in figure 3 is very adaptable, in other words it has all-around performance, in that any required emission unit can be added to it to fit the nature of the analysis performed.

3. THE QUANTIAC, A QUANTOMETRIC AUTOMATIC COMPUTER

The values indicated by the Quantolette or Quantovac do not show the actual content of the sample element, but the ratios of intensities of the line

spectra of the standard sample to other elements. To convert these values into the actual percentage content, a calibration curve must be constructed.

The calibration curve is not always a straight line. Its shape is affected by the type of element, its content, species of steel, the line spectrum used, conditions of sample excitation, types of other elements present, etc.

The Quantac is a device that 1) stores a calibration curve (usually drawn on graph paper) in memory in electronic digital form, 2) transforms the spectral line intensity as soon as it is received into the actual content, 3) gives a printout or readout of the percentage. Figure 5 shows the Quantac 502 as an example.

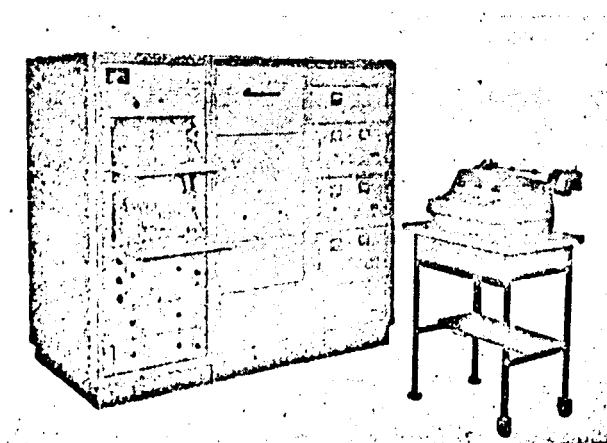


Figure 5. The Quantac 502, a Quantometric Automatic Computer (External View).

After the sample is exposed to electrical discharge, the operation of the Quantac becomes fully automatic. The selection and correction of the calibration curve, normalization of the instrument, comparison with the internal standard, etc. are all carried out automatically, without requiring an experienced operator, and only the reliable values from the analysis are teletyped immediately to the furnace. This is the latest model digital computer, which,

operating in conjunction with the Quantovac, has already been put into operation in iron and steel plants with excellent results (ref. 5).

Figure 6 shows a block diagram of the Quantac working in combination with a direct reading spectrometer.

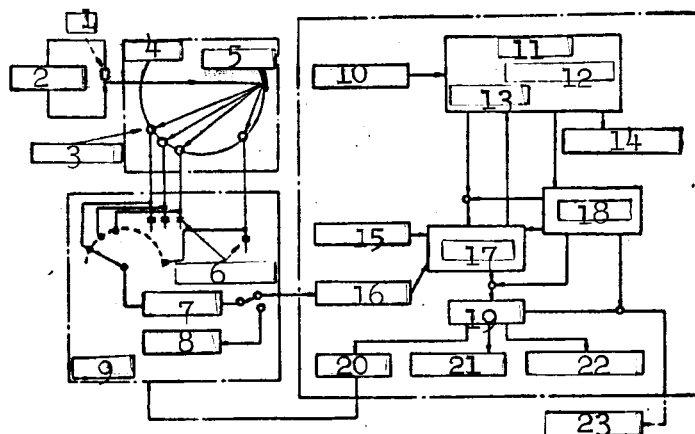


Figure 6. Block Diagram of the Quantac.

- 1) Sample; 2) Sample Excitation Equipment; 3) Photomultipliers;
- 4) Spectroscope; 5) Diffraction grating; 6) Integrating capacitors;
- 7) Amplifier; 8) Recorder; 9) Light Intensity Measuring System;
- 10) Pushbutton; 11) Memory circuit; 12) Computer program;
- 13) Calibration curve parameters; 14) Timer circuit; 15) Tape readout system; 16) Analog/digital converter; 17) Computation circuit; 18) Control circuit; 19) Output circuit; 20) Synchronizer circuit; 21) Typewriter; 22) Tape punch; 23) Furnace indicator.

The Quantac 402 is a stored-program digital computer with a memory capacity of 6400 words (where a word is a six-digit decimal number, positive or negative); the memory unit is a magnetic drum. The static circuits with transistor and diodes are filled, and the complex is designed with particular care

to maintain stability against noise disturbances elicited by sparking during excitation of the sample.

The signal from the Quantovac is fed to the analog/digital converter from the spectrometer and, after conversion to digital information, is fed to the computer input.

The results of the computation are typed and punched on the tape, whence it is sent automatically to the furnace by a transmitter, which is either open or shut according to the results of the computation.

The calibration curve parameter and other constants required for the various computations, as well as the computational results, programs for execution of the computation, etc. are all fed by pushbutton or punched tape into the memory of the computer.

When the computer begins to function, the control circuit extracts the required programs from memory and interprets them; the input circuit picks up the information from the spectrometer according to the signal delivered by the control circuit, and the computational circuit uses the information provided by the input circuit and the constant provided by the memory circuit. The intermediate result is temporarily introduced to the memory circuit and the final result is sent on to the output circuit, where it is printed out.

All of the computations, as well as the quality and sequence of operations, are designated by the computer program that is put into the memory circuit. Since the program is readily put in, extracted, revised, and augmented, the computer can be operated very flexibly. The multiple functions of the computer are summarized below:

3-1. Calibration Curve

The calibration is approximately defined by the second degree equation

$$Q = ax^2 + bx^2 + c,$$

where x is the observed light intensity and Q is the analytical value. This curve is sufficiently similar to the calibration curve that a very good approx-imate value can be obtained. 1747

3-2. Assessment of Validity of Analytical Value

A single sample is analyzed twice and the mean value teletyped only when the deviation of each analytical value does exceed a predetermined range. If the deviation exceeds this range for a given element, the result obtained for the element is typed out in red and the mean values of all the other elements are neither calculated nor transmitted.

3-3. Iron Content and Correction for Other Elements Present

In the case of high-alloy steels or binary alloys, a correction has to be introduced, because the variation in content of the base element is so large that the usual method for calculating the content of the other elements on the basis of the ratio cannot be applied.

In low-alloy steels, the carbon content affects the shape of the calibration curve for sulfur, and the curve for carbon is influenced by overlapping of the line spectra with aluminum. In these cases, the following steps can be taken as counter-measures.

- 1) Several calibration curves can be compiled for carbon and sulfur with various amounts of perturbation elements present (C in S, Al in C).
- 2) The aluminum content in the unknown sample is first analyzed and a carbon calibration curve is determined from this result with reference to the particular sample.

3) The carbon content is analyzed according to the calibration curve selected above and, simultaneously, a suitable calibration curve for sulfur is selected from the carbon analysis.

4) The sulfur content is finally determined.

3-4. Automatic Adjustment of the Calibration Curve

The operation for detecting and adjusting the variation of the calibration curve by means of a standard sample is usually performed manually (restandardization). However, a computer can manage the same operation automatically with speed and facility.

3-5. Compilation of the Inspection Report

To compile a daily or other periodic inspection report, samples recovered at random from the various furnaces are analyzed in sequence and the results fed into the computer, which classifies the data and compiles the report for the respective furnace on a single sheet of paper.

3-6. Two Quantovacs Coordinated with a Single Computer

Two or more Quantovacs are often used in one laboratory, and the information from them is handled by one computer connected to each of the Quantovacs. While the computer processes the information from one Quantovac, the other Quantovac analyzes the samples and preprocesses the analytical results for input to the computer. When the computer completes the processing for one Quantovac, the circuit is switched over at once to the other Quantovac.

3-7. Ancillary Information

By adding auxiliary circuits, signals other than the Quantovac output can be relayed to the computer. Thus a computer can perform equally well as a data logger or as a process control computer unit.

4. APPLICATION TO THE NONFERROUS METAL INDUSTRY

The aluminum manufacturers are pioneers in bringing the direct reading spectrometer into industrial chemical processing. At Alcoa, a manufacturing company in the United States, there are more than twenty spectrometers. In Japan, the direct reading spectrometer was first introduced in 1954 by Nihon Keikinzoku Kogyo (Japan Light Metal Manufacturing Company). At present, this type of spectrometer is widely used in the plants run by all of the major light metal manufacturers, including Nihon Keikinzoku Kogyo, Sumitomo Kagaku (Sumitomo Chemical Manufacturing Company), and Showa Denko (Showa Electrical Manufacturing Company). Even in smaller-scale plants, where aluminum is processed for refining, spectrometers such as the Quantolette have come into gradual use. The total number of instruments in operation in this industry comes to about twenty.

In the case of pig metal, Si, Fe, and Cu are normally analyzed, whereas in the case of aluminum-base electrical metals, Ti and Mn are also analyzed. In addition to the pig metals, the spectrometer is also used for quality control of high-purity (99.98%) aluminum or for the analysis of light alloys and slags.

Among the light alloys, Silumin, Lautal, Lo-ex, Y-alloy, and Hydronalium (casting materials), 17S, 52S, and 24S (forging materials) are analyzed, as are Cr, Cu and Ni slags.

As indicated in the preceding sections, the elements analyzed in aluminum-base metals are B, Be, Ca, Co, Cr, Cu, Fe, Li, Mg, Mn, Na, Ni, P, Pb, Si, Sn, Sb, Ti, V, and Zn.

Although comparatively few instances of the qualitative analysis of magnesium are found in Japan, in one or two plants magnesium is analyzed for Si, Mn, Ni, Cr, Cu, Al, Zn, and Fe.

The analysis of copper-base alloys has been one of the most vexing problems, in that the content of the alloying metals is so high. Sample excitation by electrical discharge in argon, however, has made accurate analysis feasible, because the influence of the matrix is almost totally eliminated.

The range of copper-base alloys that can be analyzed by the Quantolette is as follows:

Ni	0.01 - 5.0%
Si	0.01 - 6.0%
Sn	0.01 - 20.0%
Al	0.01 - 12.0%
Pb	0.01 - 1.0%
Zn	0.01 - 45.0%
Fe	0.01 - 4.0%
Mn	0.01 - 5.0%

Among the nonferrous metals, Cu, Al, Mg, Fe, Cd, Sn, Pb, Cr, Mn, Ni, and Si in zinc-base alloys, Sb, Bi, Cu, Ag, Sn, and Ni in lead and lead-base alloys, Al, Sb, As, Bi, Cd, Co, Cu, Fe, Pb, Ni, Ag, and Zn in tin are accurately analyzed. This method is also used for the analysis of materials for atomic reactors.

5. APPLICATION TO THE STEEL INDUSTRY

In Japan, small electric arc furnaces have been used for the manufacture of special steel, but recently large electric furnaces with 8-30 ton, 60 ton, and 70 ton capacities have been installed. Accordingly, the smelting output has increased, the steelmaking process has been updated, the process time has been reduced, hence the efficiency of the process as a whole has been enhanced. In view of these facts, the requirement for in situ furnace analysis of molten steel has grown commensurately.

In general, the electric furnace process of steel refining is affected by changes in the principal and subsidiary materials, the fireproofing materials, the capacity of the smelting furnace, the degree of mechanization, humidity and temperature of the atmosphere. To maintain constant quality of the product under these almost innumerable conditions, the process control becomes so complicated that in each situation proper judgment and decision-making on the part of experienced personnel are called for.

Consequently, if the conditions anent the components inside the furnace and their behavior can be detected at the right time, the result would indeed be a considerable advance, material and otherwise, in reducing the number of hours per ton of steel, economizing on material, decreasing the number of defective products, and raising the operational efficiency.

Ever since Nihon Tokushuko K. K. (Japan Special Steel Manufacturing Company) first introduced the Quantometer in 1957 for quality control of their special steels, the application of direct reading spectrometers has spread rapidly. At present, about 70 direct reading spectrometers are in operation in the steel industry.

The analysis of C, P, S, the most important elements effecting the properties of steel, has been facilitated since the Quantovac, which utilizes a vacuum spectroscope, became commercially available. It is used not only in the manufacture of special steel, but also for the open-hearth furnace and Bessemer converter. Control analysis by means of the Quantovac is carried out by all of the major steel manufacturers, for example: Sumitomo Kinzoku Kogyo (Sumitomo Metal Manufacturing Company), Yawata Seitetsu (Yawata Steel Manufacturing Company).

In particular, the increased efficiency of steel refining afforded by the converter has made not only the Quantovac, but also the Quantac indispensable in refining. In the case of steel refining by the electric furnace, analyses are conducted seven or eight times altogether, in order to control the components in 1748 the furnace according to the operational standard (i.e., once during smelting, once prior to oxygen blasting, once after oxygen blasting, once before the feed-in of ferrosilicon, once after the latter operation, once or twice after the addition of various alloying metals).

Inasmuch as these analyses are carried out synchronously with the operation of the electric furnace, the spectrometer functions on a continuous twenty-four hour basis, and the average number of elements analyzed is about 30,000 per month.

Tables 2 and 3 show the time for analysis and the number of personnel engaged in the analysis.

TABLE 2			
TIME REQUIRED FOR ANALYSIS (IN A TYPICAL STEEL PLANT)			
(Note: Analysis of 10 Elements at One Time)			
Remarks	Operation	Required time (sec)	Subtotal (sec)
Time for: transport and withdrawal of the sample preparation of the sample analysis	Withdrawal of sample	180 - 200	200 - 250
	Pneumatic transport of the sample	20 - 50	
	Cutting of the sample	50 - 60	58 - 70
	Grinding of the sample	8 - 10	
	Sample setup	13 - 15	135 - 167
	Presparking	15	
	Integrating time	20	
	Recording time	27	
	Readout time	60 - 90	
Total			393 - 487

TABLE 3

PERSONNEL ENGAGED IN ANALYSIS (IN A TYPICAL STEEL PLANT)				
Classification		Example 1	Example 2	Example 3
Engineer (day shift only)	} personnel	1		1
Foreman (day shift only)		.	1	
Operators (in three shifts)		3 x 3	4 x 3	3 x 3
Total:		10	13	10
No. of elements analyzed per month:			38,777	25,000 - 30,000

In the alloy steels, Al, As, B, C, Co, Cu, Cr, Mn, Mo, Nb, Ni, P, Pb, S, Si, Sn, Ti, V, and W are analyzed by the spectrometer. Above all, the analysis of those elements which had previously been difficult by chemical analysis, viz., Al, As, B, P, and Si, have proven particularly valuable in the factory.

The Quantovac is capable of accurately analyzing stainless steels and high-speed steels, the analysis of which had been very difficult even with conventional direct reading spectrometers. Accurate analysis is especially practicable in the case of Ni, Cr, Co, V, and W.

The extraction of the sample from the converter is limited to one or two times, because the steel is poured once every thirty minutes. At present, five elements in pig iron and more than ten elements in steel are analyzed with high accuracy by the combination of Quantovacs and a single Quantac. The advantages of the Quantac are as follows: 1) increased reliability of the analytical values due to the self-check feature; 2) shorter time for analysis; 3) fewer number of personnel (three or four people, as shown in table 3, reduced to one); 4) on-line data processing.

6. APPLICATION TO THE CAST IRON AND AUTOMOTIVE INDUSTRIES

Regular cast iron, ductile cast iron, and (of the cast steels) rolled steel are analyzed in situ in the furnace.

Since the samples for cast iron manufacturing have a high carbon content, it is essential to exercise care with the sampling matrix and casting temperature and to analyze the surface layer completely converted to white pig iron.

The elements analyzed are Al, As, B, C, Ce, Co, Cu, Cr, Mg, Mn, Mo, Ni, P, S, Sb, Si, Sn, Ti, V, and W, etc.

The analysis of carbon is rather complicated, even with the Quantovac, but the number of plants in which analysis is being carried out with success is steadily increasing.

In the case of the automotive industry, depending on the policy toward speeding up mass production, mainly the cast iron for automobiles, as well as light alloys, copper-base alloys, magnesium-base alloys, zinc die-castings, etc. are analyzed.

The test sample is withdrawn from the furnace and delivered to the laboratory by pneumatic tube. There it is set on a special grinder. After being ground on one side, the sample is conveyed on to the Quantograph. In the final step, the sample falls down through a gutter pipe immediately in front of the excitation stand. The operator picks it up and puts it on the stand. One minute after the start button is pushed, the analytical value appears on the Quantograph indicator, and another operator translates the value into the content rate and transmits the information to the processing plant via teletype. This takes a total of three minutes. At this rate, 200 samples can be analyzed during the day and 40 at night, which means an average of 1250 elements analyzed in one day.

7. CONCLUSION

The above sections refer to the application of the emission spectrometer in general, the direct reading spectrometer, Quantograph, and Quantovac in particular.

These instruments are widely used in the light metal and steel industries, and process control by means of quantometric automatic computers has been developed. However, the application of spectrometers to powder or liquid samples, despite the inherent potential of its development, has lagged, because no conclusive technique has been found for excitation of the sample.

Very shortly, slags, cement, and bauxite will be analyzed by direct reading spectrometers. The methods for excitation of a liquid sample, which have been investigated and left unresolved, are being reexamined.

The analysis by direct reading spectrometers of metallic materials has already been introduced into the Japanese Industrial Standards. Emphasis should be laid in the future on the development of techniques for withdrawal of the sample, sample preparation, analysis of powder and liquid samples, and, eventually, the analysis of nonmetallic materials.

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